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Evaluation of a Dual-frame Design to Estimate Occupancy and Productivity of Bald Eagle Nests in Kenai Fjords National Park

Natural Resource Technical Report NPS/SWAN/NRTR—2011/413

ON THE COVER
Bald eagle incubating on a nest along the outer coast, north of Ragged Island, Kenai Fjords National Park, Alaska.
Photograph by: Bill Thompson, NPS-SWAN

Evaluation of a Dual-frame Design to Estimate Occupancy and Productivity of Bald Eagle Nests in Kenai Fjords National Park

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William L. Thompson

National Park Service - Southwest Alaska Network
240 West 5th Avenue
Anchorage, Alaska 99501

Laura M. Phillips

National Park Service - Kenai Fjords National Park
P.O. Box 1727
Seward, Alaska 99664

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Abstract

The Southwest Alaska Network (SWAN) is monitoring long-term trends in nest occupancy and productivity of bald eagles in five national park units in southwest Alaska, including Kenai Fjords National Park (KEFJ). The U.S. Fish and Wildlife Service (USFWS) recently proposed a dual-frame sampling design that incorporates a double-observer component as an adjustment for nests that are missed during surveys. The double-observer portion of this design was field tested in a spring occupancy survey of bald eagle nests conducted by SWAN and KEFJ staff over nearly all of the park's coastline during May 2009. This survey also produced an updated map of occupied and empty nests in KEFJ, and estimated costs for performing this survey. As the next step in protocol development, the objectives of this study were to: 1) use information collected during the May 2009 survey to refine the sampling frame and to inform simulations for determining optimal sample unit length and sample size; 2) further evaluate the dual-frame estimator for monitoring nest occupancy and productivity of bald eagles in KEFJ; and 3) refine the techniques and standard operating procedures that will ultimately become part of SWAN's monitoring protocol for bald eagles in KEFJ. Simulation results indicated that a sample size of 25 segments of lengths of 7.8 mi or 9.3 mi should be adequate to achieve a CV of at least 12% for the estimated number of nests with incubating bald eagles in Kenai Fjords. We detected 29 nests with incubating adults, 14 of which were newly detected nests, from a random sample of 25 segments during 9-12 May 2010. Twenty-three of these nests were in Sitka spruce (*Picea sitchensis*), three were on the ground, one was in a mountain hemlock (*Tsuga mertensiana*), and one was in a balsam poplar (*Populus balsamifera*). The dual-frame estimator produced an estimate of 153 occupied nests (95% confidence interval: 88-218 nests), but this estimate is highly suspect because of the rear-seat observer's negatively biased estimate of detection probability caused by distractions related to field-testing a new data entry program. Nineteen (66%) of the 29 occupied nests contained at least one nestling during the nest productivity survey during 20-21 July 2010. Of these 19 nests, 14 had a single fledgling and five had two fledglings. There were an estimated 53 young fledged (95% Bayesian credible interval: 28-96) within the sampling frame. As an alternative to the dual-frame estimator, we propose treating our survey as a random sample of segments that contain nests with detection probabilities of one (known nests) or less than one (newly detected nests), the latter of which would be estimated via the double-observer approach. These data will be re-analyzed within a Bayesian hierarchical modeling framework with a spatial random effect added that would allow for spatially explicit estimates of nest occupancy (or nest productivity for those data).

Acknowledgments

We thank S. Lewis (U.S. Fish and Wildlife Service) and J. Schmidt (National Park Service - Central Alaska Network) for their review comments that improved this report. Many thanks to C. Lindsay (National Park Service – Southwest Alaska Network) and D. MacLean (U.S. Fish and Wildlife Service) for serving as helicopter managers for the spring occupancy and summer productivity surveys, respectively. Thanks to M. Kansteiner (Kenai Fjords National Park) for providing logistical support during our surveys. We thank R. Hodges and T. Levanger of Pollux Aviation for their excellent piloting skills. We greatly appreciate the assistance of J. Schmidt with modifying the R2WinBUGS code for estimating nest productivity. This project was funded by the National Park Service - SWAN I&M Program and Kenai Fjords National Park.

Introduction

Bald eagles (*Haliaeetus leucocephalus*) are keystone predators on avian (e.g., seabirds) and fish (e.g., salmon) populations and hence serve an important ecological role in freshwater and marine coastal systems in national parks within the Southwest Alaska Network (SWAN; Figure 1) of the National Park Service (NPS). Three of these parks, Katmai National Park and Preserve (KATM), Kenai Fjords National Park (KEFJ), and Lake Clark National Park and Preserve (LACL), contain large breeding populations of bald eagles. Nonetheless, bald eagle populations in general are under continuing threat from human-related impacts such as ecotourism, sport and commercial fishing, timber harvest, potential mining activities adjacent to the parks, and potential oil spills or other accidents along marine coastlines (Buehler 2000). Further, global climate change will have an unknown effect on their forage base and nesting habitat (e.g., see Agler et al. 1999). Consequently, bald eagles were selected as a vital sign to monitor in SWAN parks and this vital sign was rated as *highly desirable* in the prioritization process (Bennett et al. 2006).

Annual surveys of nest occupancy and productivity are commonly used to monitor raptor populations, including bald eagles (Fuller and Mosher 1987). We define nest occupancy as the presence of an adult bald eagle in an incubating posture on a nest. Bald eagles may not attempt to nest or their attempt may fail if breeding conditions are unsuitable during a given year. Their occurrence and reproductive performance may be influenced by toxic contaminants, food availability, human-related impacts, and climate (Buehler 2000). Thus, their nest occupancy and reproductive rates may be useful indicators of both current condition and long-term change of freshwater and marine coastal systems.

In KEFJ, park staff performed surveys of bald eagle nests during 1986-2002, but only surveys during 1990-2002 followed a standard protocol. Both spring occupancy and summer productivity surveys were conducted primarily on the ground (accessed via boat) during these years, except after 1997 when only occupancy surveys were conducted. In addition to lacking a correction for nests that were missed, these surveys required staff to climb steep slopes to view contents of detected nests, which raised serious safety concerns. Moreover, extreme wind conditions that commonly occur along this coastline preclude the safe use of fixed-wing aircraft at altitudes necessary to effectively survey bald eagle nests.

The U.S. Fish and Wildlife Service (USFWS) recently proposed a dual-frame sampling design (Haines and Pollock 1998) that incorporates a double-observer component (Nichols et al. 2000) as an adjustment for nests that are missed during surveys (U.S. Fish and Wildlife Service 2007). The double-observer portion of this design was field tested in a spring occupancy survey of bald eagle nests conducted by SWAN and KEFJ staff over nearly all of the park's coastline during May 2009 (Thompson et al. 2009). This survey also produced an updated map of occupied and empty nests in KEFJ, and estimated costs for performing this survey. The objectives of this study were to: 1) use information collected during the May 2009 survey to refine the sampling frame and to inform simulations for determining optimal sample unit length and sample size; 2) further evaluate the dual-frame estimator for monitoring nest occupancy and productivity of bald eagles in KEFJ; and 3) refine the techniques and standard operating procedures that will ultimately become part of SWAN's monitoring protocol for bald eagles in KEFJ.

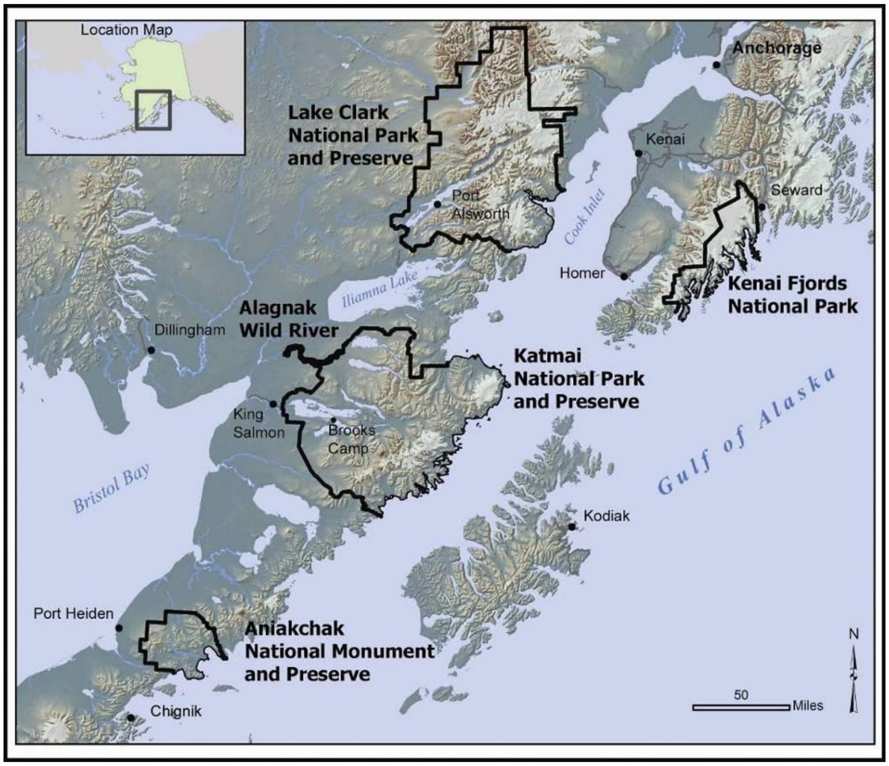

Figure 1. The five national park units within the Southwest Alaska Network (figure from Bennett et al. 2006).

Methods

Study Area

KEFJ is a 1,047 mi^2 (2,712 km^2) park located on the southeastern coast of the Kenai Peninsula in southcentral Alaska (Figure 1). The park contains approximately 500 mi (800 km) of coastline that is characterized by steep mountains reaching over 5,000 ft (1,500 m) from sea level, deep-water fjords, a rocky and convoluted shoreline, and tidewater glaciers. Half of the park is covered in glaciers. Average annual precipitation along the coast is estimated by PRISM models to range between 50-100 in (127-254 cm; Lindsay and Klasner 2009), which helps support the Sitka spruce (*Picea sitchensis*)-mountain hemlock (*Tsuga mertensiana*) forest community.

Sampling Design

We used the dual-frame design (Haines and Pollock 1998), modified to include a sightability correction for newly detected nests (U.S. Fish and Wildlife Service 2007), to estimate number of nests with incubating adult bald eagles and their associated productivity along the coast of KEFJ. A dual-frame design incorporates information from two types of sampling frames, an area frame and a list frame. An area frame is a set of spatially defined sample units (e.g., transects) that typically encompasses the population of interest, whereas a list frame is a list of specific individuals, objects (e.g., nests), or spatial units that usually are from only a portion of the area of interest. After a nest survey, nests contained in the list frame are removed from the area frame so that the latter only contains new nests. Estimates from both frames then can be combined to generate an overall estimate (see Data Analyses).

Sampling Frame

We used the flight lines generated by a GPSMap 76CSx from the 2009 spring occupancy survey of much of the park's coastline (Thompson et al. 2009) to generate the initial sample frame for the 2010 survey. The flight lines were modified within ArcGIS 9.3 (ESRI, Inc., Redlands, CA) to remove extraneous lines, to eliminate lines adjacent to extensive non-nesting habitat (e.g., heavily glaciated areas), and to combine disconnected lines. The resultant flight line was 396 mi (637.5 km). We then subdivided this flight line into 255, 1.5-mi (2.5-km) segments; these segments corresponded to the approximate length of coastline contained within the average-sized territory of bald eagles in KEFJ, based on historical nest data and interpretations of the park staff involved in these surveys (NPS, M. Tetreau, Resource Management Specialist, unpublished data). We used the 1.5-mi segment as the minimum spatial unit for creating the sample unit (see below).

Simulations to Determine Sample Unit Length and Sample Size

We chose segment lengths of 6.2 mi (10 km), 7.8 mi (12.5 km), and 9.3 mi (15 km) as potential candidates for defining sample units. This range included the side dimensions of sample units used for bald eagle surveys by the USFWS in the lower 48 states (6.2 mi; U.S. Fish and Wildlife Service 2007) and in Alaska (~8 mi; Hodges and King 1982). We used the statistical program SAS (SAS Institute, Inc., 2006, 2008) and the freeware program S-Draw (T. McDonald, WEST, Inc.; http://www.west-inc.com/computer.php) to run simulations for evaluating the optimal sample unit length and sample size to achieve a coefficient of variation (CV) of ~12% (W. L. Thompson, NPS-SWAN, unpublished data).

We conducted our simulation exercise in three steps. First, we used 68 nests with incubating adults, which was the total estimated from the 2009 survey (Thompson et al. 2009), as our true population in the simulations. We augmented the 44 occupied nests detected in the 2009 survey with a random selection of 24 nests from those detected during spring occupancy surveys conducted in the park during 1998-2000. We summed the number of nests associated with each segment length to create three spatially explicit data sets for use in the simulations. Second, we used SAS and S-Draw to select 500 generalized random-tessellation stratified (GRTS; Stevens and Olsen 2004) samples of 30 segments for each of the three candidate segment lengths. Third, we employed the simple random sample estimator in PROC SURVEYMEANS in SAS (SAS Institute, Inc., 2009) to estimate the CV of the number of nests over a range of GRTS sample sizes (n = 10-30) for the three candidate segment lengths. Note that the variance estimator based on a simple random sample overestimates the variance of a GRTS sample. Also, there were too few nests within the simulated samples to properly fit a double-observer model (Nichols et al. 2000; see Response Design), so we assumed a complete count of nests within each sampled segment, which would underestimate the variance (and CV) of the number of nests, but probably not as much as the simple random sample estimator overestimated it.

Survey Flight Logistics

We used an R44 Clipper II helicopter with fixed floats, operated via contract with Pollux Aviation, to conduct spring occupancy surveys (9-12 May) and summer productivity surveys (20-21 July) of bald eagle nests in KEFJ during 2010. The time period for the spring occupancy survey was chosen based on nest initiation data collected on >1400 bald eagle nests sampled in Prince William Sound, Alaska (USFWS, P. Schempf, Wildlife Biologist, unpublished data), whereas the time period of the summer productivity survey was at the early end of previous nest productivity surveys conducted in the park (NPS, M. Tetreau, Resources Management Specialist, unpublished data). We used Seward airport (60º07'36.98N, 149º25'07.72W) as the base of flight operations; a fuel cache was established in Beauty Bay for refueling when surveying the southwestern end of the park during the spring occupancy survey. We flew spring occupancy survey flight lines established by the 2009 survey (Thompson et al. 2009). Productivity surveys were flown from point-to-point to occupied nests that had been detected during the spring occupancy survey. Survey flights were oriented so that the left-hand side of the helicopter faced the coastline.

Response Design

Nest Occupancy

We used a double-observer method (Nichols et al. 2000) in the spring occupancy survey for adjusting counts of newly detected nests for those unknown nests that were missed in a GRTS sample of 25, 7.8-mi (12.5-km) segments. Front- and rear-seat observers on the left-hand side of the helicopter performed independent counts of nests during survey flights. Each observer waited until the nest was beyond the view of the other before announcing that it had been detected. A nest detection was only recorded after it was reconciled by both observers, and these detections were assumed to be independent between observers. We originally used a cardboard screen between observers to ensure independence (Figure 2), but removed it because it obscured too much of the view and lighting of the backseat observer (see Discussion). The front-seat observer had a wider field of view, and hence a longer time to view a given stretch of habitat, but both observers surveyed the same area. We used standard encounter history format for two sample "occasions" in a mark-recapture context (White 2008) to record which observer detected the nest, where "10" indicated the nest was only detected by the front-seat observer, "01" meant only the rear-seat observer detected the nest and "11" indicated both observers detected the nest. There were a few instances when the pilot detected a nest that was missed by both observers; in these cases the encounter histories were recorded as "00"s (see Data Analyses).

Prior to our nest occupancy survey, we plotted the nests detected during the 2009 survey into a “moving map” in ArcPad 8.0 (ESRI, Inc., Redlands, CA) on a Panasonic Toughbook. The Toughbook then was linked to a Garmin GPSMap 76CSx so that the helicopter’s location was displayed as an icon on the screen map during the survey flights, superimposed on a shapefile containing a topographic map. We used the moving map to track locations of known nests on each sampled segment and, in conjunction with nest photos, to locate them when observers did not detect them during normal survey operations.

A Garmin GPSMap 76CSx was used during aerial surveys to collect a track log of continuous GPS locations, spaced at 1-second intervals, to document flight lines. Once a nest had been detected, we recorded various attributes associated with it (Appendix A), both entered electronically using an ArcPad application (rear-seat observer; Figures 2,3) and on hardcopy data

Figure 2. The rear-seat observer holding a Panasonic Toughbook used to enter data collected during the spring occupancy survey of bald eagle nests in Kenai Fjords National Park during 9-12 May 2010. The front-seat observer recorded the same data on hardcopy forms. Note the cardboard screen taped to the seat between observers; this was initially used to ensure independence of observations (see text).

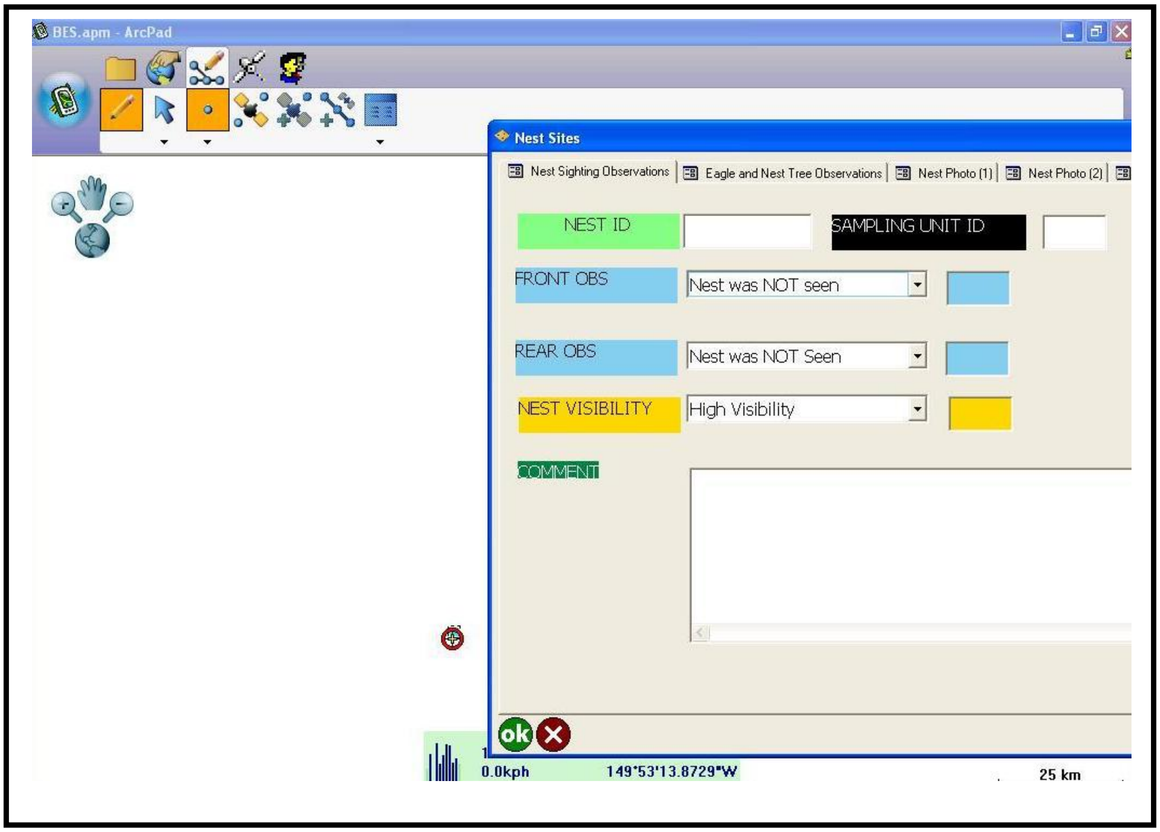

Figure 3. Screenshot of a portion of the ArcPad 8.0 data entry application used in the bald eagle nest occupancy survey in Kenai Fjords National Park during 9-12 May 2010.

forms (front-seat observer). Each nest location was marked on a moving map within the ArcPad 8.0 application described above. We recorded 0s for segments in which we did not detect a nest.

We used either a Canon EOS Digital Rebel XTi camera or a Nikon D300 digital SLR with a Nikon 80-400mm f/4.5-5.6D ED Autofocus VR Zoom Nikkor lens to take multiple digital photos of each new nest (or of a known nest with poor photos) to be used as visual aids for relocating the nest in future surveys. A Nikon GP-1 GPS accessory was attached to the Nikon camera to geotag each image with the photographer's location, whereas a picture was taken of the GPS time displayed on the Garmin unit by the Canon camera to link the GPS time to the camera’s time so that the images could be geotagged in postprocessing.

Nest Productivity

In late July, we revisited occupied nests that had been detected during the nest occupancy survey to ascertain if there were live young present and, if so, how many. Once a nest had been relocated, each observer independently surveyed the nest for young and then consulted each other to ensure their counts were consistent. Counts that did not match between observers were reconciled by further inspection of the nest. Both number of young and number of adults present at each nest were recorded on a hardcopy data form (Appendix A).

Data Analyses

Nest Occupancy

We used the non-stratified form of the dual-frame estimator in U.S. Fish and Wildlife Service (2007:26-27), which is Haines and Pollock's (1998) estimator with a detection component added, to estimate the number of nests with incubating adults in the sampling frame ($\hat{Y}$; Haines and Pollock [1998] referred to this as the screening estimator, $\hat{Y}_s$),

$$\hat{Y} = \hat{Y}_L + \hat{Y}_N,$$

where $\hat{Y}_L$ is the estimated number of occupied nests in the list frame and $\hat{Y}_N$ is the estimated number of occupied nests in the area frame that are not in the list frame. $\hat{Y}_L$ is calculated by multiplying the number of nests in the list frame (N_L) by the sample mean number of occupied nests on the list frame ($\bar{y}_L$),

$$\hat{Y}_L = N_L \bar{y}_L.$$

The estimated number of new nests ($\hat{Y}_N$) is obtained by correcting the average number of new nests in the sample ($\bar{y}_N$) by the estimated detection probability, $\hat{p}$ (see double-observer models below) and multiplying this quantity by the total number of sample units in the area frame (N_A),

$$\hat{Y}_N = \frac{N_A \bar{y}_N}{\hat{p}}.$$

The variances of the list and area frames can be added together because they are independent (Haines and Pollock 1998),

$$Var(\hat{Y}) = Var(\hat{Y}_L) + Var(\hat{Y}_N).$$

If all list frame nests are included in the survey, then $Var(\hat{Y}_L) = 0$. Otherwise,

$$Var(\hat{Y}_L) = \frac{N_L S_L^2}{n_L} - \left[\frac{N_A S_N^2}{\hat{p}^2} + \frac{N_A^2(1-\hat{p})\bar{y}_N^2}{\hat{p}^2}\right],$$

where n_L is the number of nests selected from the list frame and S_L^2 and S_N^2 are the sample variances for the list and area frame samples, respectively (U.S. Fish and Wildlife Service 2007). The variance of the area frame nests is,

$$Var(\hat{Y}_N) = \frac{N_A S_N^2}{\hat{p}^2 n_A} + \frac{N_A^2 \bar{y}_N^2 (n_p - 1) Var(\hat{p})}{\hat{p}^4 (n_A - 1)} - \left[\frac{N_A S_N^2}{\hat{p}^2} + \frac{N_A^2(1-\hat{p})\bar{y}_N^2}{\hat{p}^2}\right],$$

where n_A is the sample size chosen from the area frame and n_p is the sample size of newly detected nests (U.S. Fish and Wildlife Service 2007).

To estimate sightability (detection probability) of newly detected nests, we first constructed a candidate set of mark-recapture (double-observer) models with various individual covariates (factors) thought to affect heterogeneity in sighting probabilities of nests with incubating adults, and then used a Bayesian modeling approach with data augmentation (Royle 2009) to fit these models. The individual covariates in these models included time of day the nest was detected (PDay; percent [%] of 24 hours) and a subjective measure of nest visibility (1 = high, 2 = medium, and 3 = low). Time of day was included to address within-day observer fatigue and effects of lighting (shadows) during the early morning and late afternoon. An intercept-only (null) model was included in the candidate set; this model represented the typical mark-recapture (Lincoln-Petersen) estimator that was unadjusted for heterogeneity in sighting probabilities. We added a candidate model containing an overdispersion term (Resid) to account for extra variation (McCarthy 2007).

We employed the DIC model selection criterion (Spiegelhalter et al. 2002) to choose the best supported model for estimating sightability of nests with incubating adults. DIC can be interpreted similarly as AIC, so a model with a ΔDIC (i.e., the difference between the lowest observed DIC and a given model's DIC) of >10 indicated that it had little empirical support (Burnham and Anderson 2002).

Our implementation of this Bayesian modeling approach differed slightly from previous ones because we also included two nests that were missed by both observers (i.e., "00" observations). We did this by ensuring these two nests were part of each Markov Chain Monte Carlo (MCMC) sample by assigning an MCMC sample probability of 1 to each nest (U.S. Geological Survey, J. A. Royle, Biometrician, pers. commun). We modified the R2WinBUGS (Sturtz et al. 2005) code provided by Royle (2009) and ran it through freeware programs R (R Development Core Team. 2009) and WinBUGS (Lunn et al. 2000) to fit the Bayesian models (Appendix B). Model convergence and fit were evaluated based on the Gelman-Rubin statistic (Gelman and Rubin 1992, Brooks and Gelman 1998), visual inspection to assess proper convergence in the MCMC chains, and confirming an adequate number of effective parameters had been used.

Nest Productivity

We employed Bayesian modeling (Appendix C) to estimate the number of young fledged in the sampling frame based on nests detected with incubating bald eagles in a GRTS sample of 25 segments. This estimate was calculated by multiplying the number of segments in the sampling frame by the estimated proportion of occupied segments, the average number of nests detected with incubating adults, and the average number of young per successful nest.

Results

Simulations

Simulation results indicated that a sample size of 25 segments of lengths of 7.8 mi or 9.3 mi should be adequate to achieve a CV of at least 12% for the estimated number of nests with incubating bald eagles in Kenai Fjords (Figure 4). We chose a segment length of 7.8 mi because it required less sampling effort (i.e., shorter) and it was approximately the same length of the side of the grid cells used as sampling units by USFWS to survey bald eagles in Alaska. Therefore, we used S-DRAW to randomly select 30 GRTS samples (pixel size = 1, random number seed = 24492111), of which we used the first 24 plus the next ordered sample to fall within the northern portion of the park (segment 1) to provide a more spatially balanced sample (*n* = 25).

Nest Occupancy

We detected 29 nests with incubating adults, 14 of which were newly detected nests, from a sample of 25 segments in Kenai Fjords National Park during 9-12 May 2010 (Figure 5). Twenty-three of these nests were in Sitka spruce, three were on the ground, one was in a mountain hemlock, and one was in a balsam poplar (*Populus balsamifera*).

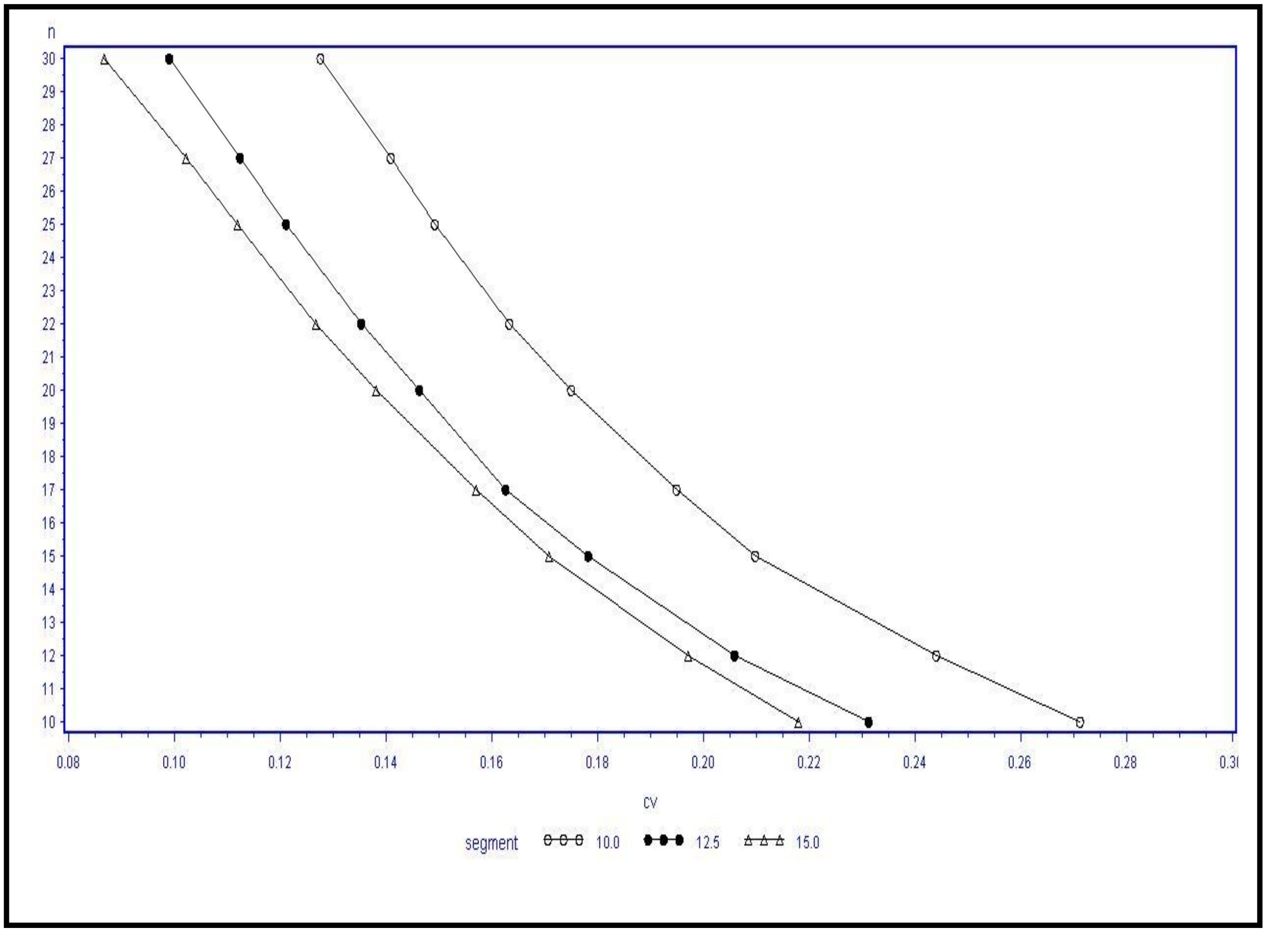

Figure 4. Results of simulations investigating the optimal size and number of sample units (segments; lengths = 6.2 mi [10 km], 7.8 mi [12.5 km], and 9.3 mi [15 km]) to achieve a CV ~ 12% for estimating number of nests with incubating bald eagles in Kenai Fjords National Park, Alaska.

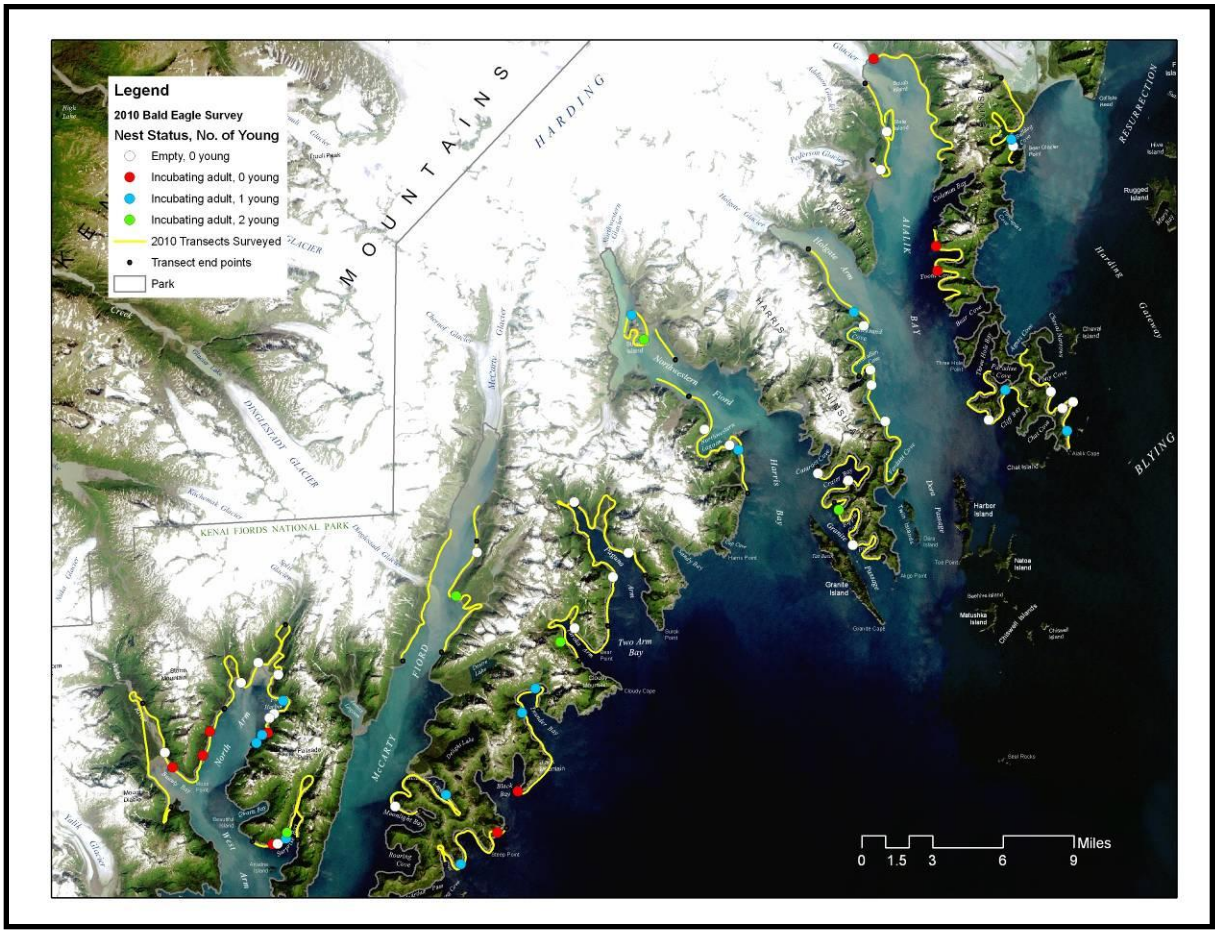

Figure 5. Locations of empty (white dots) and occupied (red, green or blue dots) nests within sampled segments along the coastline of Kenai Fjords National Park during 9-12 May 2010. Number of fledglings per occupied nest are shown in red (none), blue (1), and green (2) as recorded during a productivity survey during 20-21 July 2010.

The dual-frame estimator produced an estimate of 153 occupied nests (95% confidence interval: 88-218 nests). This included the average detection probability for new nests based on the best-fitting, double-observer model with PDAY as a covariate and prior information from the 2009 survey. The estimated detection probabilities were 0.33 (SD=0.16) and 0.10 (SD=0.07) for the front and rear observers, respectively.

Nest Productivity

Nineteen (66%) of the 29 occupied nests contained at least 1 nestling during the nest productivity survey during 20-21 July 2010. Of these 19 nests, 14 had a single fledgling and five had two fledglings (Figure 5). There were an estimated 53 fledglings (95% Bayesian credible interval: 28-96) within the sampling frame.

Discussion

An important component in developing the sample design for a monitoring program is defining the sample frame. We based our sample frame on the flight lines generated by the 2009 nest occupancy survey because they included both the coastline and coastal watersheds/river valleys that are potential nesting habitat for bald eagles. We chose to exclude areas of non-nesting habitat along the coastline, which were primarily heavily glaciated (e.g., upper McCarty Fjord; see Figure 5), to save costs. If any of these areas become nesting habitat in the future, such as from a warming climate, they can be treated as a separate stratum with their results added to those collected on the current sampling frame.

Our simulations were focused on estimating nest occupancy rather than nest productivity. Our initial sample size recommendation needs to be re-evaluated as more survey data are collected to ensure there are adequate sample sizes for detecting trends in both of these parameters. Because the GRTS Design is based on an ordered sample, if additional samples are required, they should be chosen in order. We deviated slightly from this when we chose segment 1 out of order, but a model-based analysis with a spatial component (see below) will account for this. In any event, an expanded GRTS sample from the current 30 could be generated using S-DRAW, specifying the same pixel size and random number seed used in the original settings.

The double-observer portion of this year's nest occupancy survey was complicated by the field-testing of a new ArcPad application for monitoring the location of the helicopter relative to known nest locations and to the end of segments (sample units) while performing the survey. The slowness of the Toughbook and the distraction of looking down at the moving map caused the rear-seat observer to miss nests, which biased the estimator of his detection probability downward. For instance, the estimated detection probability for this same rear-seat observer was about three times higher for the previous year's survey. This bias generated an inflated estimate of number of occupied nests (153), so this estimate is highly suspect. A better approach for analyzing these data would be to model the 2009 and 2010 data separately within the Bayesian hierarchical model through use of separate intercepts, rather then combining the two years of data via Bayesian priors as was done in this report (see below). Further, a faster Toughbook and having the pilot monitor the location of the end of the segment via his/her GPS would allow the rear-seat observer to focus on searching for nests. Then, when a nest is detected, the rear-seat observer could scan the mapped locations of known nests in that segment on the ArcPad application to identify any that may have been missed. The helicopter could return to those locations and record the data before continuing on the segment.

Another factor that likely lowered the detection probabilities of both observers was the speed of the helicopter during the nest occupancy survey. Helicopter speeds during the 2009 survey averaged 20-40 knots (37-74 km per hour), depending on wind conditions. Speeds this year were more often at the upper end of this range or higher. The negative effects of higher survey speeds are multiplied when surveying steep terrain such as that in KEFJ because observers must have a wider vertical search area than surveys in flatter terrain. Aviation safety is the most important factor when conducting aerial surveys, but when conditions safely allow, nest surveys along the KEFJ coastline should be conducted at speeds averaging 20-40 knots.

Independence of counts is an important aspect of the double observer method. We originally attached a cardboard screen between the front and back seats (left side; Figure 2) to better ensure independence. However, this obstructed more of the view of the rear-seat observer, which was already being obstructed by the fixed floats, as well as reduced the lighting, so it was removed during the first day's survey. We contend that independence can be met without this screen because the front-seat observer does not look behind and the rear-seat observer is entirely focused on searching for nests within a restricted field of view, particularly given the large vertical area that must be searched due to the steepness of the terrain.

Decay of the list frame can decrease the efficiency of the dual-frame estimator (Watts and Duerr 2010). Use of an updated list frame is preferred when employing the dual-frame estimator, but in our case, it was cost prohibitive to revisit the all nests detected during the 2009 spring occupancy survey (Thompson et al. 2009), both occupied (n = 44) and empty (n = 36), over the entire sampling frame to obtain an updated number of occupied nests on the list frame in 2010 (i.e., the N_L in the formulas on page 7). Therefore, we used the number of occupied nests detected in 2009 and assumed it was reasonably close to the number occupied during 2010. We could expand our sample mean of occupied nests from the 2010 spring occupancy survey to generate an estimated total number of occupied nests ($\hat{N}_L$), but this adds another source of variation, i.e., the dual-frame estimator on page 7 assumes N_L is a known constant. As an alternative to the dual-frame approach, we propose treating our survey as a random sample of segments that contain nests with detection probabilities of one (known nests) or less than one (newly detected nests), the latter of which would be estimated via the double-observer approach. These data could be analyzed within a Bayesian hierarchical modeling framework without need of the dual-frame estimator or the total number of nests on the list frame. Moreover, a spatial random effect could be added to these Bayesian hierarchical models that would allow for spatially explicit estimates of nest occupancy (or nest productivity for those data). A measure of spatial adjacency would have to be developed to inform this spatial component, but would allow for estimates of unsampled segments as well. This will be part of the next step in our development of a monitoring protocol.

Another step in the development of a protocol for monitoring nest occupancy and productivity of bald eagles in KEFJ would be the use of simulations to determine how often surveys need to be performed to be able to detect a specified trend. This will require additional years of data to better gauge annual rates of nest occupancy and productivity. If these rates are generally high, then less frequent surveys will be required. At least 5 years of pilot data may be needed to address this question, and perhaps more.

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Appendix A: Revised Data Forms for Bald Eagle Nest Occupancy and Productivity Surveys

SWAN Bald Eagle Nest Occupancy Data Sheet Page _____ of ______

Date: ___________ **Park:**_______________ **Recorder:** ______________________ **Pilot:** ___________________________

Front Observer:_____________________ **(L or R)** **Rear Observer:**_________________ **(L or R)** **Aircraft:** ________________________

(Circle Left [L] or Right [R] position in front and rear seats.)

S. Unit ID	Nest ID	Front Obs.	Rear Obs.	No. Ads.	Eagle Behav.	Nest Occup.	Nest Substr.	Tree Status	Tree Form	Nest Visib.	GPS Time	Comments

Sampling (S.) Unit ID:	Enter unique numeric code for the sampling unit being surveyed (enter "Alpha code – Null – S. Unit ID" for null segments, e.g., "NU-Null-48")
Nest ID:	Enter alphanumeric nest identification code (NO-#, AI-#, NW-#, OU-#, or NU-#)
Front Observer (Obs.):	Enter 1 if nest was seen or 0 if nest was not seen by front observer (or Not Applicable [NA] if known nest).
Rear Observer (Obs.):	Enter 1 if nest was seen or 0 if nest was not seen by rear observer (or Not Applicable [NA] if known nest).
No. of Adults (Ads.):	0, 1, 2, Not Applicable (NA)
Eagle Behavior:	Nesting (N), Flying (F), Perching (P), Nesting and Flying (NF), Nesting and Perching (NP), Flying and Perching (FP), Not Applicable (NA)
Nest Occupancy:	Empty (E), Incubating (I), Not Applicable (NA)
Nest Substrate:	Spruce (S), Hemlock (H), Cottonwood (C), Ground (G), Not Applicable (NA)
Nest Tree Status:	Live (L), Dead (D), Live with Large Dead Branches (LD), Not Applicable (NA)
Nest Tree Form:	Normal Complete Top (NT), Abnormal Complete Top (AT), Broken Live Top (BL), Broken Dead Top (BD), Not Applicable (NA)
Nest Visibility:	1 (High visibility), 2 (Medium visibility), 3 (Low visibility), Not Applicable (NA)
GPS Time	Hour:Minute:Second in 24-hour format (e.g., 14:03:32 for 2:03:32 pm)

SWAN Bald Eagle Nest Productivity Data Sheet

Page _____ of ______

Date: ___________ **Park:**______________ **Recorder:** ____________________ **Pilot:** _________________________

Front Observer:____________________ **Rear Observer:**________________ **Aircraft:** ______________________

Nest ID	No. of Young	No. of Adults	Comments

Nest ID: Enter alphanumeric nest identification code (NO-#, AI-#, NW-#, OU-#, or NU-#)
No. of Young: 0, 1, 2 , 3
No. of Adults: 0, 1, 2

(Version 5/26/2010)

Appendix B: R2WinBUGS Code for Using Bayesian Hierarchical Models with Data Augmentation to Fit Double-observer Data and Covariates

Appendix B. The following R2WinBUGS code uses prior data with a data-augmented, Bayesian hierarchical model (Royle 2009; Biometrics 65:267-274) to fit covariates for a time-of-day, nest visibility, and an overdispersion term to the detection functions of both observers from double-observer data. This model can be modified to run simpler covariate models shown in Table 2. The more complex models such as the one below requires more MCMC samples, longer burn-ins and larger thinning rates than the simpler models.

```
# Specify the total number of MCMC samples (ni), the burn-in (nb), the
# thinning rate (nthin), the number of MCMC chains (nc), number of data
# augmented observations (nz) and number of nests detected (nind). The
# actual MCMC samples selected = (ni-nb)/nthin .

dobs.fn=function(ni=1100000,nb=100000,nthin=50,nc=3,nz=61,nind=14){

# This program is for previously undetected nests with incubating adults detected during
# helicopter surveys from a sample of the KEFJ coastline during 9-12 May 2010. The two
# individual covariates thought to induce heterogeneity in detection probability are percent of 24-
# hour day at the time a nest was detected (PDay) and a subjective measure of nest visibility
# (NestVis; 1=high, 2=medium, 3=low). [Note: NestVis replaces TreeP from the 2009
# analysis.] An overdispersion factor is also added. Parameters for the informed priors were
# based on those generated from the best-fitting model from the previous year's (2009) analysis.
# The two observers were on the left side of the front and back seats of the R44 Clipper II
# helicopter.

# Analysis Notes (2010 data):
#
# 1) Because only 2 of the 3 categories (high and medium) of
# NestVis were observed for new nests detected during the 2010
# occupancy survey in KEFJ, this covariate was recoded as 0 (medium)
# or 1 (high) so that the current code could be used (i.e., replaces TreeP,
# which was coded 0,1 in the 2009 analysis).
#
# 2) The priors for the intercept and beta parameters in the
# separate logit models for each observer were based on 2009 data,
# with the precision increased by 33% to allow for a more diffuse
# prior. Alternatively, both years of data could be analyzed together,
# indexed by year.
#
# 3) The same rear-seat observer was used for both surveys (2009 and
# and 2010), but different front-seat observers were used. However,
# both front-seat observers were well-trained and had much experience
# so their detection models were assumed to be similar across years.

library("R2WinBUGS")

# Set the working directory on your computer.
```

```
setwd("C:/Bill/Dobs_Analysis/Model_1_global")

# Import the text file containing the data and specify the variables
# (covariates).

data<-read.table("BAEANestDat2010.txt")
PDay<-vector(mode='numeric',length=length(data[,1]))
PDay<-data$PDay
NestVis<-vector(mode='numeric',length=length(data[,1]))
NestVis<-data$NestVis

ncap<-as.matrix(data[,1:4])

sink("model.txt")
cat("
model {

# Assign distributions to the various model parameters

psi~dunif(0,1)
psi2~dunif(0,1)
tau~dgamma(.01,.001)           # precision of normal distn for random effect

mub2<- -1.1                    # specify mean of posterior distn for beta2 (PDay) from previous
                               #    analysis
sigmab2<- 3.5                  # specify SD of posterior distn for beta2 (PDAY) from previous
                               #    analysis, increased by 33%
sigb2sq<- sigmab2*sigmab2      # sigma-squared for beta2 (PDay)
precb2<- 1/sigb2sq             # precision for beta2 (PDay)

mu1.pe<- 0.8                   # specify mean of posterior distn for mu1.p (int, Observer 1
                               #    model) from previous analysis
mu2.pe<- -0.03                 # specify mean of posterior distn for mu2.p (int, Observer 2
                               #   model) from previous analysis
sigmu1.pe<-2                   # specify SD of posterior distn for mu1.pe from previous
                               #   analysis, increased by 33%
sigmu2.pe<- 2                  # specify SD of posterior distn for mu2.pe from previous
                               #   analysis, increased by 33%
sigmu1sq<- sigmu1.pe*sigmu1.pe    # sigma-squared for sigmu1.pe
sigmu2sq<- sigmu2.pe*sigmu2.pe    # sigma-squared for sigmu2.pe
mu1.peprec<- 1/sigmu1sq         # precision for mu1.pe (intercept for observer 1 model)
mu2.peprec<- 1/sigmu2sq         # precision for mu2.pe (intercept for observer 1 model)

mu1.p~dnorm(mu1.pe,mu1.peprec)    # prior for mu1.p (PDay) based on 2009 results
mu2.p~dnorm(mu2.pe,mu2.peprec)    # prior for mu2.p (PDay) based on 2009 results
```

```
beta1~dnorm(0,0.01)            # specify a diffuse prior for beta1 (NestVis; a new variable in
                               #    2010)
beta2~dnorm(mub2,precb2)       # prior for beta2 (PDay) based on 2009 results

# Use a Bernoulli distribution with mean psi (aka
# Binomial distribution with 1 trial) to generate
# the probability that the first 13 observations
# (observed nests) will be sampled via MCMC

for(i in 1:13){
z[i]~dbin(psi,1)}

# Assign the next observation (00 entry - nests missed by
# both observers but seen by pilot = observation no. 14)
# a probability of 1 for being sampled via MCMC

for(i in 14:14){
z[i]~dbin(1,1)}

# Sample from the data augmented observations (obs 15-75)

for(i in 15:(nind+nz)){
        z[i]~dbin(psi,1)
}

for(i in 1:(nind+nz)){

# Fit one the categorical variable with a Binomial
# distribution with 1 trial (=Bernoulli)

  NestVis[i]~dbin(psi2,1)

# Assign a uniform distribution to the continuous
# covariate PDay for the data augmented missing values
# Use the range of observed values to set the bounds

  PDay[i]~dunif(.38,.72)

# Assign normal distribution to random effect

e[i]~dnorm(0,tau)I(-5,5)

# Fit individual covariates to logit model of detection probabilities
# of two observers
```

```
  logit(p1[i])<-  mu1.p  + beta1*(NestVis[i])  + beta2*(PDay[i])  + e[i]
  logit(p2[i])<-  mu2.p  + beta1*(NestVis[i])  + beta2*(PDay[i])  + e[i]

  cp1[i]<-  (1-p1[i])*p2[i]
  cp2[i]<-  p1[i]*(1-p2[i])
  cp3[i]<-  p1[i]*p2[i]
  cp4[i]<-  (1-p1[i])*(1-p2[i])

  mu[i,1]<-z[i]*cp1[i]
  mu[i,2]<-z[i]*cp2[i]
  mu[i,3]<-z[i]*cp3[i]
  mu[i,4]<-z[i]*cp4[i]  + (1-z[i])

  ncap[i,1:4]~dmulti(mu[i,1:4],1)
}

# Back transform  the avg detection probs for each
# observer, evaluated  at NestVis=1  (high)  and at the  average
# PDay value  (=0.572)

logit(p1bar)<-mu1.p  + beta1 + beta2*(0.572)
logit(p2bar)<-mu2.p  + beta1 + beta2*(0.572)

Nind<-sum(z[1:(nind+nz)])

}
",fill=TRUE)
sink(
data<-list("ncap","nind","nz","NestVis","PDay")
zst<-c(rep(1,nind),rbinom(nz,1,.25))
inits<-function(){
      list(mu1.p=0,mu2.p=0,beta1=rnorm(1),z=zst)
}
parameters <- c("Nind","beta1","beta2","mu1.p","mu2.p","p1bar","p2bar","psi","z")

out <- bugs(data, inits, parameters, "model.txt", n.thin=nthin,n.chains=nc,n.burnin=nb,n.iter=ni,
          bugs.directory="/Program Files (x86)/WinBUGS14",debug=TRUE)

out
}
dobs.fn()
```

Appendix C: R2WinBUGS Code for Using a Bayesian Approach to Estimate Number of Young Fledged at Bald Eagle Nests in the Sampling Frame

Appendix C. The following R2WinBUGS code estimates the number of young fledged from bald eagle nests across the entire sample frame (i.e., all segments covering the survey area of interest) in Kenai Fjords National Park. The data are from the summer productivity survey conducted in the park during 20-21 July 2010. The template for this program was written by Mike Conroy (Univ. of GA) and extensively modified by Bill Thompson (NPS-SWAN) and Josh Schmidt (NPS-CAKN).

```
# Specify the total number of MCMC samples (ni), the
# burn-in (nb), the thinning rate (nthin), the number of
# MCMC chains (nc), number of segments surveyed (n_f),
# number of successful nests (n_y), and number of segments
# from which a sample of size n_f was drawn (nsegm).

library("R2WinBUGS")

# Set the working directory on your computer.

setwd("C:/Bill/BAEA_KEFJ/2010_Nest_survey/Nest_Productivity/Analysis")

# Import the text file containing the data and specify the variables

data<-read.table("ThompsonW_2010_KEFJ_BAEANestProdData_20101110.txt")

# Y = number of young fledged on surveyed segments with nests with
# incubating adults. (Note: list the data on segments with nests with
# incubating adults first and then populate the rest of this column
# with NAs

Y<-vector(mode='numeric',length=length(data[,1]))
Y<-data$Y

# truncate Y vector to only include surveyed segments
# with at least 1 nest with an incubating adult (17 in this case)

Y<-Y[1:17]

# F = number females (nests) detected on a given surveyed segment

F<-vector(mode='numeric',length=length(data[,1]))
F<-data$F

# Indicator variable (x) for surveyed segements with at least 1 nest
# with an incubating adult (x=1) or none (x=0). This variable
# also can be generated internally to this program (rather than read
# in) with a little extra code.
```

```
x<-vector(mode='numeric',length=length(data[,1]))
x<-data$x

'nest.fn'<-function(ni=120000,nb=20000,nthin=10,nc=3,n_f=25,n_y=17,nsegm=51)

{

sink("model.txt")
cat("

model {

# set priors for lambda_f, lambda_y and lambda0

lambda_f~dgamma(0.01,0.01)
lambda_y~dgamma(0.01,0.01)
lambda0~dnorm(0,tau0)
sigma0~dunif(0,100)
tau0<-1/(sigma0*sigma0)

# loop across all surveyed segments

for (i in 1:n_f){

#proportion of occupied segments
   x[i]~dbern(p[i])
   logit(p[i])<-lambda0

#numbers of nesting females
   F[i]~dpois(lambda_f)
}

# loop across successful nests

for (i in 1:n_y){
#young per successful nest
  Y[i]~dpois(lambda_y)
}

#estimated total number of young fledged for all segments

nestocc<-(exp(lambda0))/(1+exp(lambda0))
Y_tot<-lambda_f*lambda_y*nestocc*nsegm

}
```

```
",fill=TRUE)
sink()
data<-list("Y",  "F","n_y","n_f","x","nsegm")
p<-rep(0.5,n_f)   # create vector of initial  values  for p
inits<-function(){
      list(lambda_f=1,lambda_y=1,lambda0=0.7)}

parameters  <- c("Y_tot","nestocc","lambda0","lambda_f",  "lambda_y")
out <- bugs(data,  inits,  parameters,  "model.txt",n.thin=nthin,n.chains=nc,n.burnin=nb,n.iter=ni,
          bugs.directory="/Program  Files  (x86)/WinBUGS14",debug=TRUE)

out

}

nest.fn()
```

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